Universal Library of Innovative Research and Studies | Research Article

ISSN: 3065-0003 | Volume 2, Issue 3

Open Access | PP: 68-72

DOI: https://doi.org/10.70315/uloap.ulirs.2025.0203011

Optimizing Delivery Routes in Postal Logistics Using Mobile Apps and AI

Natalia Maliarchuk

Nova Poshta, Manager, Norway, Oslo.

Abstract

This article presents an analysis and systematization of contemporary methods for optimizing delivery routes based on the use of mobile applications and AI-based solutions. The aim of the study is to develop a conceptual hybrid model that combines predictive analytics of machine learning with dynamic real-time route adjustment, relying on data obtained from couriers' mobile devices. The methodology encompasses a comprehensive systematic review of scientific publications dedicated to solving the vehicle routing problem (VRP), as well as a comparative analysis of the performance of various algorithmic approaches in the field of AI. As a result, the hybrid adaptive model for route optimization (HAMRO) is described, in which genetic algorithms are employed for the initial generation of an optimal plan, and reinforcement learning methods ensure operational route adaptation under changing road and logistical conditions. The results presented in this article will be of interest to researchers in the field of transport logistics, developers of software for delivery services, and managers of postal and courier companies focused on enhancing the efficiency of operational processes.

Keywords: *Postal Logistics, Route Optimization, Vehicle Routing Problem, VRP, Artificial Intelligence, Mobile Applications, Last Mile, Machine Learning, Genetic Algorithms, Reinforcement Learning.*

INTRODUCTION

Under the current stage of global economic development, postal logistics is experiencing unprecedented pressure due to the rapid expansion of the e-commerce segment. According to expert estimates, by 2026 the total volume of the global e-commerce market may reach 8.1 trillion US dollars [1], which inevitably leads to an increase in the number of shipments and parcels. The most resource-intensive and technologically complex stage of delivery is recognized as the last mile [2].

Traditional route-planning algorithms, based on static address allocation and predefined trajectories, lose effectiveness under conditions of high order concentration, variability of road conditions, and dynamic customer requirements. The absence of integrated models capable not only of calculating optimal routes at the planning stage but also of adapting them in real time in consideration of multiple stochastic factors creates a significant scientific and practical gap.

The aim of this work is to develop a conceptual hybrid model that combines machine-learning predictive analytics with dynamic real-time route adjustment, relying on data obtained from couriers' mobile devices.

The scientific novelty of the work lies in formulating a hybrid adaptive model that integrates real-time data from mobile applications with a multi-agent architecture based on reinforcement-learning methods for predictive and dynamic route adjustment.

It is hypothesized that the implementation of the proposed model into the operational processes of postal services will significantly reduce operational costs and delivery time compared with existing static and classical dynamic approaches.

MATERIALS AND METHODS

The growth of e-commerce and the tightening of consumer requirements for delivery speed have created the problem of optimising last-mile routes. On the one hand, global trends show a steady increase in the volume of online trade, both in the USA and worldwide, which is confirmed by recent industry statistics [1]. On the other hand, it is precisely the last kilometres that remain the most expensive and complex in the logistics chain: the high density of addresses, short delivery times and constant changes in route conditions require innovative technical solutions [2].

Citation: Natalia Maliarchuk, "Optimizing Delivery Routes in Postal Logistics Using Mobile Apps and AI", Universal Library of Innovative Research and Studies, 2025; 2(3): 68-72. DOI: https://doi.org/10.70315/uloap.ulirs.2025.0203011.

A number of review studies systematise and classify the main approaches to formulating and solving vehicle routing problems (VRP). Tan S. Y., Yeh W. C. [11] propose a broad taxonomy of classical VRP models, including versions with time windows, loading-unloading operations and dynamic changes in conditions. Zhang H. et al. [10] focus not only on models but also on algorithmic paradigms—from exact branch-and-bound methods to hybrid heuristics. In turn, Li H., Zhou J., Xu K. [9] perform a bibliometric analysis of green versions of VRP, emphasising the growing interest in environmental criteria when constructing routes.

In the segment of heuristic and metaheuristic methods, significant achievements are associated with flexible adaptation strategies and multi-criteria problem statements. Li J., Liu R., Wang R. [3] develop an adaptive algorithm that makes it possible to introduce adjustments in a timely manner during delivery. Ibrahim M. F. et al. [12] improve the classical GA by including specialised crossover and mutation operators for pick-up-and-delivery scenarios with strict time windows, which improves the quality of solutions with moderate computational time. Mohammed A., Al-Shaibani M. S., Duffuaa S. O. [4] develop a metaheuristic for multilayer supply networks taking into account several objectives at once—cost, reliability and delivery time—which expands the classical VRP to more complex multilevel chains. Zhang Y., Wang L. [5] proposed using self-organisation mechanisms that rapidly reconfigure trajectories under changing loads on the delivery network.

The emergence of artificial-intelligence methods, especially deep learning and big-data analytics, opens new horizons for processing information flows in real time. Olayinka O. H. [6] emphasises the role of integrating big data and analytical platforms to monitor fleet operation and adaptive decision-making based on data from drivers' mobile devices and vehicle sensors. In the same vein, Pan W., Liu S. Q. [7] apply deep reinforcement learning to the dynamic VRP, formulating an agent-training strategy capable of independently developing a routing policy under uncertainty and in real time.

Among exact methods, a branch-and-price algorithm for the VRP with the use of unmanned aerial vehicles developed by Zhou H. et al. [8] stands out. This approach provides provable optimality of solutions on relatively small scales, which is important for specialised drone-delivery services. Nevertheless, computational complexity limits its application in large-scale dynamic routing tasks.

Thus, it can be seen that the literature on route optimisation in recent years has evolved from classical VRP surveys to modern hybrid algorithms and AI solutions. Meanwhile, the following contradictions and shortcomings are observed:

- heuristic methods (GA, ACO) demonstrate high solution-generation speed but often lag behind AI approaches in adaptability to unforeseen changes.

- exact algorithms that guarantee optimality are limited to small scales and are poorly compatible with real-time dynamic updates.

- green VRP pay attention to environmental factors but rarely take into account the operational requirements of mobile applications and user preferences.

At the same time, the following aspects are poorly covered: integration of optimisation algorithms with mobile applications for end users (interface, user experience, notifications of delays and route changes); issues of data security and confidentiality when collecting telemetry; real piloting of solutions in postal-service projects; and inter-operator coordination within a single urban space. These areas represent promising directions for further research.

RESULTS AND DISCUSSION

The results of the analysis and the identified scientific gaps constituted the starting point in the development of the conceptual hybrid adaptive model for route optimization (Hybrid Adaptive Model for Route Optimization, HAMRO). The aim of the model is to overcome the shortcomings of existing systems through a hierarchical two-level architecture and active use of streaming real-time data. The key idea of HAMRO lies in the clear delineation of strategic (global) and tactical (local) planning functions.

At the strategic level, initiated before the start of the operational cycle, the vehicle routing problem (VRP) is solved for the entire delivery pool. The core is an enhanced algorithm which, unlike traditional implementations, operates not only on coordinates and time windows but also on predictive metrics. These metrics are generated by a machine learning module based on gradient boosting that analyzes historical data on traffic at different times of day, average parking time and parcel handover at specific locations (data collection is performed via the courier mobile application). This approach enables the construction of not simply the shortest route but the statistically most efficient one[5, 7].

At the tactical level, a multi-agent system based on reinforcement learning methods (Multi-Agent Reinforcement Learning, MARL) is applied. Each courier acts as an autonomous agent whose task is the maximization of the reward composed of the number of timely completed deliveries and minimal mileage. In real time the agent receives data on its location, road conditions via mapping service APIs and new urgent orders, which allows it to promptly adjust the sequence of the nearest 2–3 delivery points. The central system establishes the framework for agent interaction and prevents potential conflicts [9, 12]. The architectural scheme of the model is presented in figure 1.

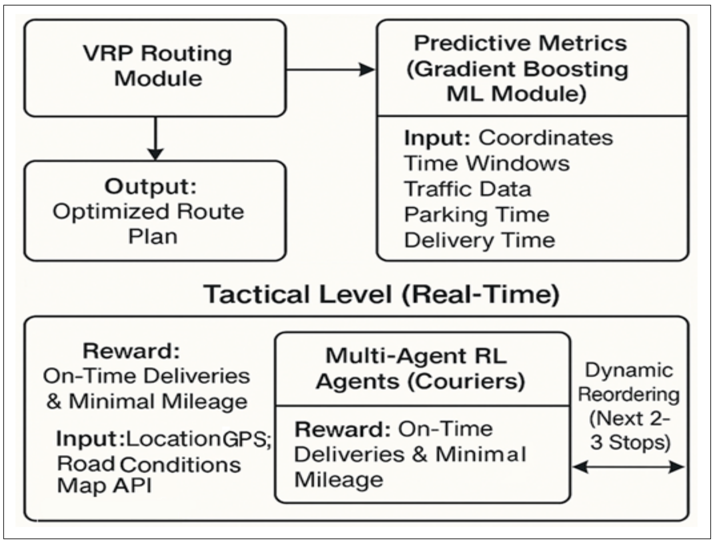

Fig. 1. Model architecture (compiled by the author based on the analysis of [5, 9, 12]).

The presented scheme indicates that the central element is the bidirectional transmission of data between the mobile application and the AI core. The mobile client not only receives the plotted route but also continuously returns telemetry, which serves both for immediate tactical adjustments and for the strategic training of the predictive model, thereby forming a closed loop of its continuous refinement.

For the quantitative evaluation of the HAMRO model's potential, two baseline strategies are employed, as illustrated in figure 2.

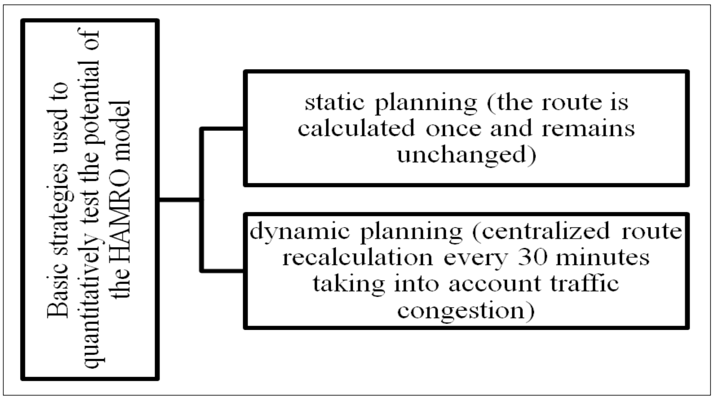

Fig. 2. Basic strategies used to quantitatively test the potential of the HAMRO model (compiled by the author based on the analysis of [3, 4, 8]).

The greatest contribution to service quality improvement is made by a significant reduction in the proportion of delay events, which is critically important for postal logistics. This effect is explained by the fact that the HAMRO model implements proactive adaptation to changing transport conditions rather than being limited to reacting to congestion that has already occurred. The system's predictive module is capable of identifying potentially problematic segments in advance and generating alternative routes before a traffic jam has time to form.

One of the fundamentally significant properties of the system under consideration is its capacity for autonomous self-improvement. The application of a reinforcement learning approach provides agents (couriers) with the opportunity for the gradual accumulation of empirical knowledge, which ultimately leads to the identification of optimal local routing strategies. The effectiveness of this process is demonstrated through a graphical representation of the trend in fuel consumption – an indirect indicator of travel efficiency – over several training iterations (equivalent to hypothetical months of system operation) [3, 4, 10].

Analysis of the obtained data indicates that the practical implementation of HAMRO is associated with a number of significant challenges. These include increased requirements for computational resources to simultaneously execute the genetic algorithm and support multiple RL agents. The need for reliable integration with the operator's existing IT systems (CRM, WMS) and the critical human component: couriers must not only be trained to use the mobile application but also be confident in the correctness of the proposed routes. At the same time, the projected economic benefits — reduction in fuel expenditures, increased courier efficiency, and, most notably, enhanced customer loyalty due to delivery accuracy and speed — substantially outweigh the costs of implementation [6, 11].

The advantages, disadvantages, and future trends in delivery route optimization in postal logistics using mobile applications and AI algorithms are presented in Table 1.

Table 1. Advantages, disadvantages and future trends of delivery route optimization in postal logistics using mobile applications and AI algorithms (составленоавторомнаосновеанализа[6, 10, 11]).

Component	Advantages	Disadvantages	Future trends
Mobile applications	- Real-time telemetry collection (GPS coordinates, delivery status) in real time - User-friendly interface for the courier: change notifications, route visualization - Instant communication with the central system and the client	- Dependence on network quality and coverage (data loss, latency) - High energy consumption and device resource requirements - Security and confidentiality risks during transmission of user data	- Development of 5G/edge computing to reduce device-side latency and energy consumption - Implementation of explainable AI (XAI) in the mobile client for transparency of routing decisions - Integration of telemetry with AR interfaces to optimize courier operations and visual support
Genetic algorithms (GA)	- Efficient global-optimum search under multiple constraints (time windows, load) - Flexibility in accounting for diverse criteria (cost, environmental impact) - Rapid generation of initial route plans	- Possible convergence to local optima without guarantees of global optimality - Sensitivity to parameter tuning (population size, mutation/crossover operators) - Increased computational complexity as the number of delivery points grows	- Parallelization on GPU and cloud clusters to accelerate computations - Automated hyperparameter optimization (AutoML approaches) - Hybridization with heuristics (ACO, Tabu Search) and ML modules for predictive population initialization
Reinforcement learning (MARL)	- Adaptation to dynamic changes in traffic conditions and urgent orders in real time - Multi-agent interaction model (coordination of agents/ couriers) - Gradual accumulation of empirical knowledge and improvement of local routing strategies	- Prolonged training and large data requirements for agent training (data-hungry) - Risk of unstable learning and performance regressions due to environmental changes - High resource requirements at the tactical level (multithreading, low latency)	- Improved sample efficiency (off-policy methods, transfer learning) - Federated RL to ensure courier data privacy - Simulation-based “digital twins” for safe and rapid agent training without intervention in real operational environment
Hybrid adaptive model (HAMRO)	- Synergy of strategic (GA + predictive analytics) and tactical (MARL) levels - Significant reduction of delays through proactive route adjustment - Closed-loop learning: telemetry feeds predictive modules and RL agents	- Complexity of integrating diverse AI components and ensuring coordinated operation - Increased IT infrastructure requirements (cloud services, API gateways, fault tolerance) - Need for staff training and changes in business processes	- Microservice-based and cloud-native architecture for modularity and scalability - Implementation of XAI components to enhance trust among logisticians and couriers - Expansion via integration with unmanned vehicles (drones, delivery robots) and IoT sensors
Predictive analytics (Gradient Boosting and Big Data)	- High accuracy of traffic and dwell-time predictions based on historical data - Ability to account for seasonality, time windows and local route characteristics - Improved strategic planning quality through predictions of traffic “hot spots”	- Dependence on the quality and volume of historical data (gaps, noise) - Potential model drift in a rapidly changing environment - Labor-intensive maintenance and updating of ML pipelines (data engineering, model monitoring)	- Shift to online learning (streaming ML) for continuous model updates with new data - Automation of ML pipelines (MLOps) for rapid deployment and version control of models - Integration with XAI systems for forecast interpretation and support in decision-making

The proposed model does not constitute a replacement for the logistician but rather an intelligent decision-support tool that relieves the specialist of routine tasks and enables concentration on the strategic management of the logistics network. In contrast to a number of existing approaches, this solution is based on the synergy of two distinct types of AI algorithms, which ensures the exploitation of each method’s strengths to address tasks at various levels and represents the key advantage and scientific novelty of the system.

CONCLUSION

The analysis conducted made it possible to organize and systematize the existing methods for solving the route optimization problem in postal logistics, as well as to identify directions for their development, primarily related to the implementation of mobile solutions and artificial intelligence tools. A review of specialized publications revealed that, despite the active testing of individual methodological approaches — from genetic algorithms to reinforcement learning models — there are no comprehensive hybrid platforms capable of simultaneously providing long-term strategic planning and flexibly adapting to changes in the operational environment in real time.

As an achievement of the study, a conceptual two-level hybrid adaptive model for route optimization (HAMRO) is presented, combining genetic optimization methods with predictive analytics at the strategic stage and a multi-agent system based on reinforcement learning at the tactical stage. This approach provides a synergistic effect: strategic route planning is complemented by operational correction in response to sudden changes, thereby eliminating the limitations of both purely static and simplified dynamic solutions.

Prospects for further research lie in the practical testing of the HAMRO model on the example of a specific postal-logistics operator, as well as in expanding functionality through integration with unmanned vehicles and drones. In addition, the area of increasing the transparency of AI-component decisions through the development of explainable AI (XAI) methods remains relevant, which ultimately contributes to strengthening user trust and the effectiveness of system implementation among logistics specialists.

REFERENCES

1. Ecommerce Statistics in 2025 (Latest U.S. and Global Data). [Electronic resource] Access mode: https://ecommercetips.org/ecommerce-statistics/ (date of access: 05/10/2025).
2. The challenging logistics of last-mile delivery. [Electronic resource] Access mode: https://www.dhl.com/global-en/delivered/global-trade/challenging-logistics-of-last-mile-delivery.html(date accessed: 13.05.2025).
3. Li J., Liu R., Wang R. Elastic strategy-based adaptive genetic algorithm for solving dynamic vehicle routing problem with time windows //IEEE Transactions on Intelligent Transportation Systems. – 2023. – Vol. 24 (12). – pp. 13930-13947.
4. Mohammed A., Al-Shaibani M. S., Duffuaa S. O. A meta-heuristic-based algorithm for designing multi-objective multi-echelon supply chain network //Applied Soft Computing. – 2023. – Vol. 147. https://doi.org/10.1016/j.asoc.2023.110774
5. Zhang Y., Wang L. A Dynamic Scheduling Method for Logistics Supply Chain Based on Adaptive Ant Colony Algorithm //International Journal of Computational Intelligence Systems. – 2024. – Vol. 17 (1). – pp. 1-6.
6. Olayinka O. H. Big data integration and real-time analytics for enhancing operational efficiency and market responsiveness //Int J Sci Res Arch. – 2021. – Vol. 4 (1). – pp. 280-96.
7. Pan W., Liu S. Q. Deep reinforcement learning for the dynamic and uncertain vehicle routing problem // Applied Intelligence. – 2023. – Vol. 53 (1). – pp. 405-422.
8. Zhou H. et al. A branch-and-price algorithm for the vehicle routing problem with drones //Optimization Online. – 2022. - pp. 1-5.
9. Li H., Zhou J., Xu K. Evolution of green vehicle routing problem: A bibliometric and visualized review // Sustainability. – 2023. – Vol. 15 (23). –pp. 1-27. https://doi.org/10.3390/su152316149
10. Zhang H. et al. Review of vehicle routing problems: Models, classification and solving algorithms //Archives of Computational Methods in Engineering. – 2022. – pp. 1-27.
11. Tan S. Y., Yeh W. C. The vehicle routing problem: State-of-the-art classification and review //Applied Sciences. – 2021. – Vol. 11 (21). – pp. 1-28. https://doi.org/10.3390/app11211029.
12. Ibrahim M. F. et al. An improved genetic algorithm for vehicle routing problem pick-up and delivery with time windows //Jurnal Teknik Industri. – 2021. – Vol. 22 (1). – pp. 1-17. https://doi.org/10.22219/JTIUMM.Vol22.No1.1-17